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Spatial and temporal variation of methane emissions in drained eutrophic peat agro-ecosystems: drainage ditches as emission hotspots

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Abstract

Our research investigates the spatial and temporal variability of methane (CH₄) emissions in two drained eutrophic peat areas (one intensively managed and the other less intensively managed) and the correlation between CH₄ emissions and soil temperature, air temperature, soil moisture content and water table. We stratified the landscape into landscape elements that represent different conditions in terms of topography and therefore differ in moisture conditions. There was great spatial variability in the fluxes in both areas; the ditches and ditch edges (together 27% of the landscape) were methane hotspots whereas the dry fields had the smallest fluxes. In the intensively managed site the fluxes were significantly higher by comparison with the less intensively managed site. In all the landscape element elements the best explanatory variable for CH₄ emission was temperature. Neither soil moisture content nor water table correlated significantly with CH₄ emissions, except in April, where soil moisture was the best explanatory variable.

1 Introduction

It is of great importance to assess the contribution of the trace gas methane (CH₄) to the greenhouse gas effect and the related global warming. Northern peatlands are believed to be significant sources of CH₄, estimated to emit between 20 and 50 Tg yr⁻¹ (Mikaloff Fletcher et al., 2004a, 2004b). In northern oligotrophic and eutrophic managed peatland systems, net uptake and emission rates have been found to depend on groundwater level, soil moisture content, temperature, and grassland management (Blodau and Moore, 2003; Christensen et al., 2003; Hendriks et al., 2007; Hargreaves and Fowler, 1998; Pelletier et al., 2007; Van den Pol-Van Dasselaar et al., 1998a). CH₄ emissions are difficult to estimate because of their large spatial and temporal variability. Furthermore, there are two major challenges when upscaling: selecting the correct ecosystem variables for the stratification and developing predictive relationships (Groffman et al., 2000).

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In the Netherlands, eutrophic peatlands have been drained for centuries and in the last 50 years peatlands have been drained more deeply to make agriculture possible, resulting in peat oxidation. These peatlands are therefore major carbon sources of CO₂ (Langeveld et al., 1997; Schothorst, 1977; Veenendaal et al., 2007). Burgerhart (2001) and Van den Bos (2003) have suggested that peat oxidation can be reduced if agricultural peatlands are transformed into wetland nature by raising the water table and by reducing agricultural intensity, thus altering the carbon cycle and probably turning sources into sinks. There is great uncertainty, however, about the impact of such measures on the CH₄ balance. Hendriks et al. (2007) found that in an area in the centre of the Netherlands where intensive farming had ceased 14 years previously and the water table had risen, a very small sink of 71 g CO₂-equiv m⁻² yr⁻¹ had developed. They attributed this to a decrease in CO₂ emissions and an increase in CH₄ emissions from ditches and waterlogged soil however, they had no data from the pre restoration situation.

We investigated spatial and temporal variability of CH₄ emissions in two drained peat areas – one intensively managed and the other less intensively managed – and examined the correlation between CH₄ emissions and soil temperature, air temperature, soil moisture content, water table and management over almost two years. We monitored CH₄ flux measurements at discrete points within landscape elements representing different micro topographical conditions. We aimed to determine the mean flux associated with the landscape element, and to provide a spatially integrated flux measurement for the study areas. We compared the annual CH₄ emission balances of both areas.

2 Materials and methods

2.1 Site description

The experimental sites (Oukoop, intensively managed dairy farm and Stein, less intensively managed) are located in a polder in the west of the Netherlands (Coord.

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52°02'01" N" 04°46"E" and 52°01'07"N" 04°46"E") (Fig. 1). The climate is temperate and humid, with mean annual precipitation of about 800 mm and an annual long-term mean temperature of 9.8°C. Nol et al. (2008) calculated that 21% of the polder is open water (ditches and small permanent pools) 6% is ditch edges (waterlogged land bordering the ditches), <2% is drainage trenches (located in the middle of the field, containing water in winter) and >71% is drier land with a fluctuating water table. The soils consist of a clayey peat or peaty clay top layer of 25 cm overlying 12 m eutrophic peat deposits. The polder is below sea level: its mean elevation is between 1.6 and 1.8 m below the Amsterdam Ordnance Datum (NAP). The depth to the groundwater varies from 70 to 15 cm; perched water tables occur after heavy rain, when the soil impedes water infiltration. Both sites have been described in detail by Veenendaal et al. (2007).

As Stein has become a bird reserve, its management is less intensive than previously. Intensive dairy farming on the two experimental parcels of land here was stopped more than 20 years ago. During the measurement period, both parcels were used as hayfields; they were mown three times after 15 June each year (2005, 2006 and 2007). The water table has been allowed to fluctuate since 2006, with a high water table (20 cm below field level) in winter. In both plots, the average C and N contents in the top 20 cm of the soil are 15% and 1.3%, respectively. In most of the parcels of land in Stein, *Lolium perenne* is dominant, often with *Poa trivialis* co-dominant. Over time, *Holcus lanatus*, *Anthoxanthum odoratum* and *Rumex acetosa* have become more abundant.

The Oukoop experimental plots are situated on an intensive dairy farm. The management regime varies per year, but overall consists of mowing three times a year and manuring and fertilizing three times a year. The average C and N contents in the top 20 cm of the soil are 24% and 2.4%, respectively. Here too, *Lolium perenne* is the most dominant species and *Poa trivialis* is co-dominant.

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2.2 Field sample points

Two land parcels were used for this experiment: one intensively managed and the other less intensively managed. At the beginning of January 2005, 6 PVC collars (diameter 30 cm) were installed in the middle of each parcel, so that gas emissions could be sampled. The measurements were carried out from January 2005 to September 2007.

From February 2006 until September 2007, 19 additional sampling points, distributed over two different land parcels per location, were sampled at both research locations to study spatial variability. We stratified both locations into four landscape elements with differing soil/water temperature and soil moisture conditions: permanently water-filled ditches, ditch edges, narrow drainage lines or trenches in the middle of the fields, and the field area with fluctuating water table (henceforth referred to as “field”). In each of the two fields, there were four sample points in the ditches, four points in the ditch edges, two or three sample points in the drainage trenches and eight or nine sample points in the fields.

2.3 Chamber measurements

Fluxes of CH₄ were determined using a modified closed chamber method (Hutchinson and Mosier, 1981). Gas flux was measured using a Photo Acoustic Field Gas Monitor (INNOVA 1412 sn, 710-113, ENMO services, Belgium) connected by Teflon tubes to a PVC chamber (Van Huissteden et al., 2005). Samples were taken from the headspace of the closed, dark chamber (30 cm diameter, 25 cm height) that was placed on a collar. A small fan was installed in the chamber to homogenize the inside air and a water lock was placed to control inside pressure. On land we used water between the chamber and the collar to seal the chamber from the ambient air during the measurement. At the ditches we used floaters and a lever system to gently lower the chamber onto the water surface, carefully avoiding the effect of pressure differences. We used external silica gel and soda lime filters to minimize cross-interference of CO₂ and water vapour with methane at high concentrations. Our gas analyser was calibrated and tested for

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drift every year at the NMI (Nederlands Meet Instituut: Delft, The Institution of Standards). Occasional cross-checks with a standard calibration gas established that the instrument did not drift. All measurements were taken during the day, between 8 a.m. and 4 p.m. Each flux measurement consisted of five point-measurements taken at one-minute intervals.

In addition to each flux measurement, soil or water temperature was measured at 10 cm depth and soil moisture content was determined in the top 5 cm of soil at the sample points, using a HH2 Delta-T device (Delta T Devices, Llandindrod Wells) calibrated for the soil type. The water table was recorded with pressure sensors installed in a steel frame to a depth of 70 cm into the soil at one or two places in the field (e+ sensor L-50, Eijkelkamp Agrisearch Equipment BV, Giesbeek, Netherlands). Water levels were logged hourly. Any gaps in the data were filled with average values from other sensors in the surrounding area.

2.4 Calculations and statistical analyses

CH₄ fluxes were calculated using linear regression of the changes in concentration over time, because the closure times of the chambers were short. First, the data quality was assessed: outliers resulting from disturbances, chamber leakage or instrument failures were removed from the data set. Annual mean net CH₄ emissions were estimated by trapezoidal integration of mean net CH₄ emission over time (design-based approach, Van den Pol-Van Dasselaar and Oenema, 1997; Velthof et al., 1996) and by linear regression of natural logarithm-transformed CH₄ data (model-based approach, Hendriks et al., 2007).

The statistical significance of differences between landscape elements within sites was calculated with one-way ANOVA; analysis of covariance, with temperature as covariate, was used to ascertain the statistical significance of differences in the fluxes from the landscape elements of the two sites. Correlations between natural logarithm-transformed emissions and independent variables were calculated using step-wise multiple linear regression analysis (case-wise elimination of variables). Statistical

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analyses were carried out with SPSS.

For the calculations of the contribution of animals and manure on the intensive dairy farm, we used the method with simple emission factors as described by Hensen et al. (2005). Though the most recent IPCC report (IPCC, 2007) mentions a global warming potential (GWP) of 25 to convert CH₄ emissions to CO₂ equivalents, we used a (GWP) of 23 for CH₄, at a 100-year time horizon (IPCC 2001, UNFCCC/CP/1997/7/Add.1/Decision2/CP.3, e.g. Lashof et al., 2000) to allow comparisons to be made with other research.

3 Results

3.1 Seasonal and spatial variation of methane fluxes

We compared the landscape elements for the period that measurements of emissions from all landscape elements ran parallel (January 2006 to September 2007). The average soil moisture content and air temperature during this period are shown in Fig. 2: highest temperatures were in July and August and lowest temperatures in December and January.

Emission rates varied greatly, depending on the time of the year. For instance, at both sites in 2006 and 2007, ditch emission rates were highest in June, July, August and September; field emission rates were highest in March, April, May and June (Fig. 3). We also observed that in February 2006 emission rates were slightly higher from the intensively managed site after thaw and manure application. There was a seasonal effect: over 85% of the total annual CH₄ emissions were observed in summer and maximum emission rates in ditches were ten times those of the fields. Ditches showed episodic, exceptionally high emission values: for example in 2006 on 27 and 28 September: 366.05 (*n*=6) and 123.8 (*n*=4) mg m⁻² hr⁻¹ for the intensively managed and less intensively managed areas, respectively. During these measurements we observed turbulent water surface conditions. Emission rates also varied over the years

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for both sites: maximum ditch emissions were higher in 2007 than in 2006 whereas maximum edge emissions were higher in 2006 than in 2007.

Spatially, the fluxes from edges and ditches differed significantly between the two sites: in the intensively managed site they were up to 1.5 and 3 times higher, respectively (Fig. 3). At both sites, the CH₄ fluxes from the ditches (21% of the area) were significantly greater than those from the fields, ditch edges and drainage trenches ($P<0.01$). At both sites, the fluxes from the ditch edges (6 % of the landscape) were significantly greater than those from the fields ($P<0.01$). The lowest emissions were from the fields (>71% of the landscape surface area). The emission rates of drainage trenches (<2% of the landscape) did not differ significantly from the emission rates of fields and ditch edges.

3.2 Temperature, soil moisture and the dependence of the methane fluxes on water table

The ditches in both sites showed a positive correlation ($r^2=0.259$; $P<0.01$; $n=74$ and $r^2=0.295$; $P<0.01$; $n=77$, respectively) between the Ln-transformed CH₄ emissions (hereafter LnCH₄) and water temperature and also a significant positive correlation ($r^2=0.221$; $P<0.01$; $n=67$ and $r^2=0.216$; $P<0.01$; $n=57$, respectively) between LnCH₄ emissions and air temperature (Fig. 4).

In both sites there was a significant, positive correlation between LnCH₄ emissions from fields and soil temperature ($r^2=0.212$; $p<0.01$; $n=171$ and $r^2=0.091$; $p<0.01$; $n=178$, respectively) and an even stronger positive correlation ($r^2=0.371$; $P<0.01$; $n=117$ and $r^2=0.226$; $P<0.01$; $n=169$, respectively) between LnCH₄ emissions and air temperature (Fig. 4).

Overall, the correlations of CH₄ emissions with soil moisture were weak in both the intensively and the less intensively managed sites. Adding moisture in a stepwise regression did not significantly improve the predictive power of the regression. However, analysing the dataset month by month revealed an exception for April in 2006 and

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2007, when soil moisture appeared to be a stronger predictor for the emission rates at both sites (Fig. 5).

The water table in both sites fluctuated greatly during the measurement period: it was high (−15 cm) in winter and low (−65 cm) in summer. The water table did not show any significant correlation with CH₄ emissions from the fields.

The CH₄ emissions from ditch edges correlated significantly with soil temperature, but the best explanatory variable was air temperature (Fig. 4). The correlation between emission rates and soil moisture in the edges of our fields was not significant, except for April in the less intensively managed site where again a significant positive correlation occurred ($r^2=0.862$; $P<0.05$; $n=7$).

3.3 Annual methane balances

For the estimation of annual terrestrial CH₄ balances we used 2 methods: (1) trapezoidal integration over time (for 2005, 2006 and 2007) and (2) linear regression with temperature as explanatory variable (for 2006) (Table 1). The regression-based estimates are based on hourly air temperature data. Fluxes were estimated per landscape element and multiplied by the area occupied by the landscape element, providing a spatially integrated flux measurement. Emissions from drainage trenches were not used in the calculations of the annual CH₄ balance because their contribution is negligible. Comparison of the fluxes estimated by these two methods sometimes revealed large differences.

In the fields, integrated annual fluxes based on the daytime measurements were higher but of comparable magnitude to the estimates from regression. However in the ditches and ditch edges, large episodic venting events, in the ditches mainly caused by turbulent water, caused averages to be up to 20 times higher. Even when these are excluded, the mean values are much higher than the values estimated from regression. Our exclusive use of daytime measurements might have resulted in overestimation of methane fluxes. We estimated regression-based methane fluxes for two days and found that when using data between 12 p.m. and 4 p.m. only, the estimated daily

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methane fluxes were higher: by up to 45% on a winter day and up to 50% on a summer day. Regression-based estimated methane fluxes at different times on 21 December and 4 July are given in Fig. 6.

3.4 Field methane emissions compared to farm-based emissions

5 It is interesting to compare measured field methane emissions with farm-based emissions. We estimated farm fluxes using emission factors for dairy cows (E_d), heifers (E_y), calves (E_c), manure (E_s) and farmyard manure (FYM) (274, 170, 48, 53 and 40 g CH₄ day⁻¹ animal⁻¹ or m⁻³, respectively) as described by Hensen et al. (2005). Using these factors, emission (Q) from the farm was calculated as:

10
$$Q = (\text{No. Dairy}) \times E_d + (\text{No. Heifers}) \times E_y + (\text{No. Calves}) \times E_c + (m^3 \text{Slurry}) \times E_s + (m^3 \text{FYM}) \times E_f$$
 (Table 2)

15 The farm emission (467 kg CH₄ ha⁻¹ yr⁻¹) is estimated to be ~64% of the total emission when terrestrial emissions (258 kg CH₄ yr⁻¹) are included in the balance. For this calculation we used the regression-based values from table 1, multiplied by the farm size: 50 ha.

4 Discussion and conclusions

4.1 Ditches and edges: methane hotspots in eutrophic, drained peatlands

20 In both sites, the ditches and ditch edges (which together account for 27% of the total landscape) turned out to be CH₄ hotspots. As Table 1 shows, linear regression revealed that in the intensively managed site they emitted 6.3 and 4.4 times more CH₄, respectively than the dry field; this compares with 1.7 and 2.5 times more in the less intensively managed site.

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The CH₄ emission rates from the permanently water-filled, 30–60 cm deep ditches could be predicted by water temperature or air temperature. The exceptionally high emission peaks (up to 800 mg m⁻² hr⁻¹ in the summer) may have resulted from ebullition events, during which CH₄ quickly passes through the top layer in the water column where oxidation can take place, but they probably mainly occurred when both water temperature and wind velocity were high. In a peatland study in Central Finland, Minkinen and Laine (2006) found that the methane fluxes from ditches with flowing water were generally higher than from ditches with standing water. They argued that the diffusion rates were higher in flowing water because when water is turbulent the boundary layer is thinner. The contribution of very high fluxes to the annual balance may lead to overestimation in the integration-based approach. Even when using a regression-based approach, annual averages of methane emission must be presented with some caution. Our comparison of trapezoid integrated calculated means and the regression-based temperature-dependent calculations highlights the uncertainty in the means: for example, all the flux measurements were performed during the day, so when trapezoid calculations were used, the fluxes may have been overestimated due to diurnal temperature changes when integrating over time (cf. Mikkilä et al., 1993; Chanton et al., 1993). It will be recalled that when using data from 12 p.m. to 4 p.m. only, we found that the daily methane fluxes were 45% higher on 21 December (winter) and 50% higher on 4 July (summer).

Our results demonstrate that field emissions are an exponential function of soil and air temperature: the regression-based fluxes in the intensively managed site were statistically significantly higher in 2006 and 2007 despite varying soil moisture contents. The seasonal distribution of emission rates varied between sites. In the less intensively managed site, high CH₄ fluxes were concentrated in the summer period, while in the intensively managed site they were concentrated in early spring and summer, partly associated with field applications of slurry. Van den Pol-Van Dasselaar et al. (1999) also reported higher CH₄ emissions after manure application (but the increase they found was not statistically significant). We would argue that the reason for the enhanced CH₄

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production is the combination of wet soil, the application of easily decomposable organic material and the anaerobic conditions in the slurry. The only month for which we found significant correlation between soil moisture and CH₄ emission rates was April – the period when the field begins to dry out after being waterlogged in winter and when air temperature may rise rapidly from 10 to 25°C. The correlation between depth to water table (65 to 15 cm) and CH₄ fluxes at both sites was not significant: the highest fluxes occurred at intermediate and sometimes high water tables. In both sites the water table fluctuated not only seasonally, but also because of hydraulic regulation by the Dutch water board. In both sites, the impermeable soil prevented water from infiltrating after heavy rain, resulting in perched water tables in winter. The large variation in the water table could explain the weak correlation between water table and CH₄ emissions.

Ditch-edge CH₄ fluxes correlated significantly with soil and air temperature, but not with soil moisture content except, as in the fields, for April (positive correlation). At both sites the edge fluxes were significantly higher than the field fluxes. The edges border the ditches and so were damp for most of the year, with soil moisture contents >60%. These damp conditions give rise to a different vegetation than in the dry fields: in some places *Iris pseudacorus* and *Typha angustifolia* are present. These aerenchymatic plants might cause additional fluxes because CH₄ diffuses rapidly through their stems.

4.2 Methane fluxes in other peatland ecosystems

Our measurements showed that both our drained sites are a net source of CH₄ the annual regression-based means were 258 and 114 kg ha⁻¹ for the intensively managed site and less intensively managed site, respectively. These values are in the same order of magnitude as fluxes found in other managed and unmanaged peatland ecosystems (Table 3). Van den Pol-Van Dasselaar et al. (1998a), who studied CH₄ emissions in grassland on peat soils in a nature reserve elsewhere in the Netherlands, reported great spatial variability; though the emission values in fields were similar to ours, the emission rates they found in saturated land were higher.

It is particularly interesting to compare our results with those reported by Hendriks

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et al. (2007) for a site some 35 km from our research area. They studied the full greenhouse gas balance of a peatland on comparable soils that had not been intensively farmed for >10 years but left unmanaged, with a high water table. Their estimated total weighted (per landscape element), regression-based annual methane flux of 417 kg ha⁻¹, was higher than both our estimated, weighted regression-based annual methane fluxes: 258 and 114 kg ha⁻¹ for the intensively and less intensively managed sites, respectively. The estimated annual emission rate of 18.72 mg m⁻² hr⁻¹ in ditches reported by Minkkinen and Laine (2006) is also higher than the regression-based fluxes from our ditches. The extremely high emission rates from ditches found by Minkkinen and Laine (2006) and by Bubier et al. (1993) were similar to the extreme values we found at turbulent water conditions. However, when we took account of the farm-based emissions (which are ~64% of total emissions), our estimated annual methane flux was 725 kg ha⁻¹ in the intensively managed site. Compared with the values found in formerly intensively farmed peatland (Hendriks et al., 2007), this estimated annual methane flux is ~42% lower, whereas the fluxes from our less intensively managed site are ~84% lower.

For the total balance (i.e. CO₂ plus CH₄) we used data from Veenendaal et al. (2007) who performed CO₂ eddy correlation measurements in our intensively and less intensively managed sites. The intensively managed site had a net annual CO₂ emission of 122 g C m⁻², whereas the less intensively managed site had a net annual CO₂ uptake of 57.6 g C m⁻². The resulting annual sources obtained when the terrestrial annual methane emissions were included (using global warming potentials of 23 for CH₄, IPCC 2001) were of 567 and 138 g C m⁻² CO₂ eq, respectively. The restored site studied by Hendriks et al. (2007) was found to be a very small sink of 269 g C m⁻². These estimates of the total balance in the intensively and less intensively managed sites do not include nitrous oxide (N₂O) emissions. The N₂O fluxes found for the restored site were negligible.

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4.3 Conclusion

Our study has demonstrated the value of stratifying the landscape when calculating annual CH₄ balances. We found that in managed, eutrophic peat areas, the ditches and their adjacent saturated edges are CH₄ emission hotspots. However, the results were not clearcut, due to the occurrence of episodic emission under turbulent water conditions in ditches. It can be concluded that by comparison with less intensively managed areas and restoration areas, the intensively managed area is a large source of methane when farm methane fluxes are included.

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Table 1. Estimates of annual CH₄ fluxes (kg ha⁻¹) for the intensively and less intensively managed sites by trapezoidal integration and linear regression.

	Year	Intensive management		Less intensive management	
		integration	regression	integration	regression
Field	2005	98	–	98	–
	2006	174	112	150	92
	2007	221	–	48	–
Ditch	2005	–	–	–	–
	2006	1508	702	1895	158
	2007	2501 ^a	–	2130 ^a	–
Edge	2005	–	–	–	–
	2006	2398	492	1,307	226
	2007	778 ^a	–	538 ^a	–
Total	2005	–	–	–	–
	2006	587	258	586	114
	2007	733 ^a	–	515 ^a	–

^a for the last two months of 2007 we used values from 2006.

– not enough data yet to estimate a year balance.

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Table 2. Estimated emissions from the intensive farm ($\text{kg CH}_4 \text{ day}^{-1}$) using the simple emission factor approach as described by Hensen et al. (2005). Emission factors are those estimated by Van Amstel et al. (2003) and Sneath et al. (2006).

	Emission factor ($\text{g CH}_4 \text{ day}^{-1}$)	Number (No)	Volume (m^3)	Calculated emission ($\text{kg CH}_4 \text{ day}^{-1}$)
Dairy cow (Ed)	274	65	–	17.81
Heifer (Ey)	170	20	–	3.4
Calf (Ec)	48	10	–	1.44
Manure (slurry) (Es)	53	–	780 ^a	41.34
Farmyard manure (FYM)	40	–	0	0
Total emission ($\text{kg CH}_4 \text{ day}^{-1}$)				63.99

^a Calculated from herd size and a production of $12 \text{ m}^3 \text{ manure adult animal}^{-1}$ for the whole winter period.

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Table 3. Comparison between the CH₄ emission rates in this study and the CH₄ emission rates reported in other studies on peatland ecosystems. Mean CH₄ emission rates are in mg CH₄ m⁻² hr⁻¹ and the three last columns on the right represent the landscape elements.

Ref.	Ecosystem	field	edge/ saturated land	ditch/pond
Minkkinen and Laine (2006)	Boreal fen	–	–	18.72 up to 25 in summer
Hendriks et al. (2007)	Less eutrophic fen	1.6	15.3	5.6
Bubier et al. (1993)	Boreal fen	0.0–1.0	–	5.8 up to 38.2 in summer
Bellisario et al. (1999)	Less eutrophic fen	1.0–10.0	–	–
Pelletier et al. (2007)	Boreal fen	0.1–0.9	1.2–8.2	–
Liblik et al. (1997)	Boreal fen	–	2.0–9.2	–
Van den Pol-	Less eutrophic fen	0.9–2.3	11.8	–
Van Dasselaaar et al. (1998b)				
Waddington and Day (2007)	Less eutrophic fen	–	–	2.9
Adrian et al. (1994)	Eutrophic aquifer	0.0–8.0	–	
Huttunen et al. (2003)	Boreal fen	–	–	up to 8.0
Hamilton et al. (1994)	Less eutrophic fen	–	–	4.6–7.5
Chanton et al. (1993)	Less eutrophic fen	–	5.3–12.4 (aerenchym plants)	–
Schrier-Uijl et al. (this study)	Eutrophic fen	1.12	4.92	8.69
Schrier-Uijl et al. (this study)	Eutrophic fen	0.92	2.26	4.20

– no emission rates available

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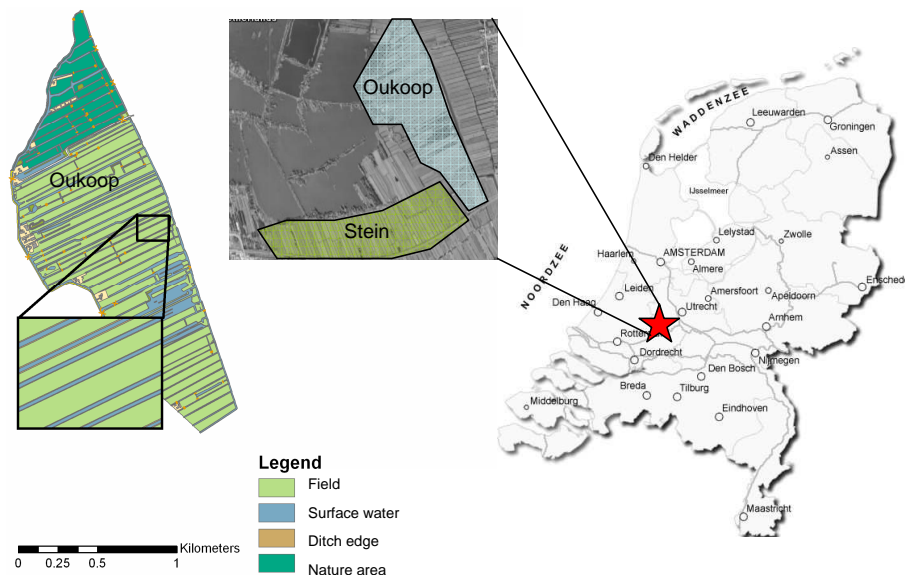


Fig. 1. The location of the intensively and less intensively managed areas in the Netherlands (right) and a close up (middle) of the intensively managed area (Oukoop) and the less intensively managed area (Stein). The insets on the left are close-ups of Oukoop (the intensively managed area): they show the characteristic parcellation of the polder landscape in more detail: long, narrow land parcels bounded by ditches (by Nol et al., 2008).

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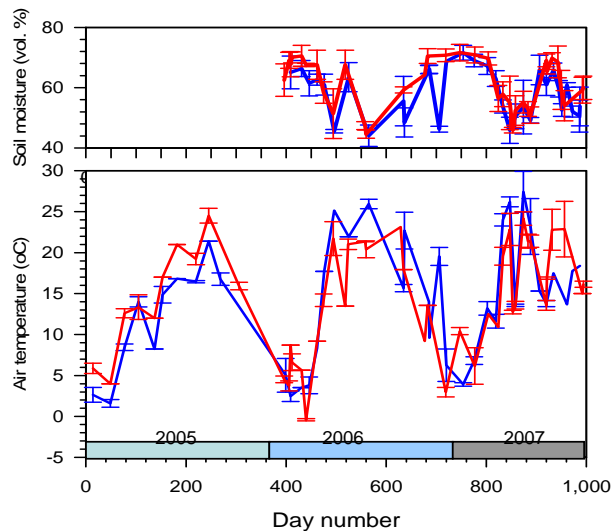


Fig. 2. Average (mean \pm SD) soil moisture content (vol%) and air temperature ($^{\circ}$ C) for the intensively managed (red) and less intensively managed (blue) areas from day 0 (1 January 2005) to day 994 (21 September 2007).

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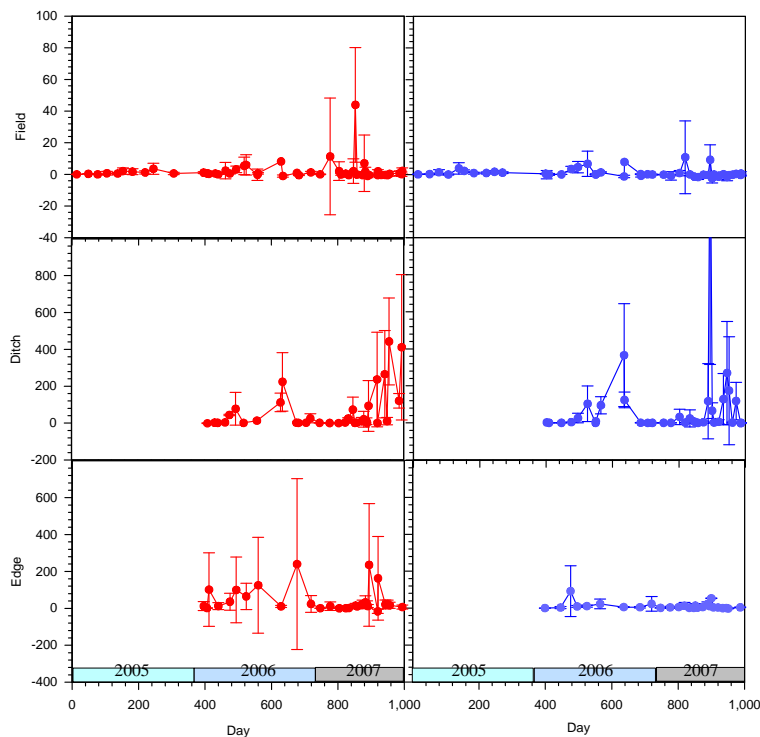


Fig. 3. Temporal variability of mean methane fluxes ($\text{mg m}^{-2} \text{hr}^{-1}$) in the various landscape elements for the intensively (left) and less intensively managed (right) sites from day 0 (1 January 2005) to day 994 (21 September 2007). Error bars show standard error of the mean.

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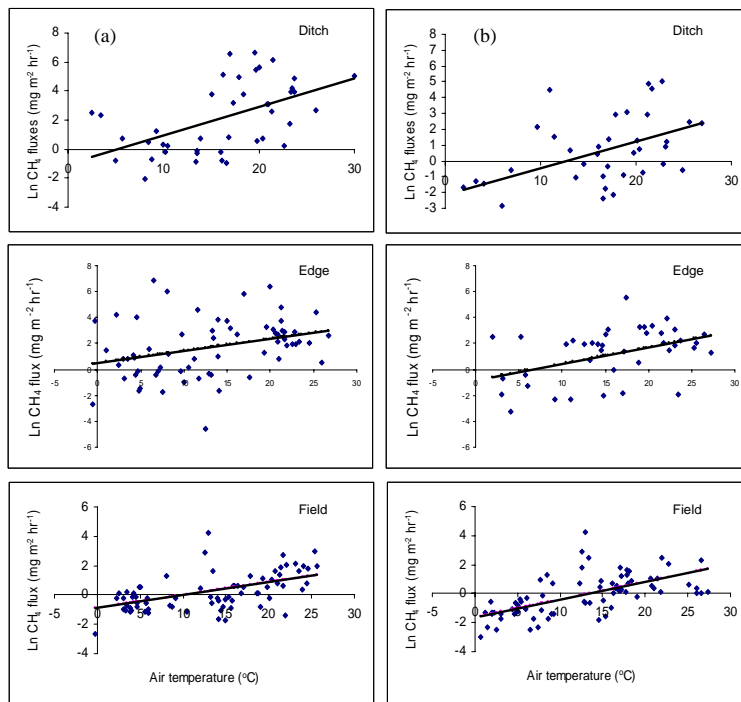


Fig. 4. Relationship between ditch, edge and field LnCH₄ fluxes and air temperature; individual points and regression lines for **(a)** the intensively managed site and **(b)** the less intensively managed site.

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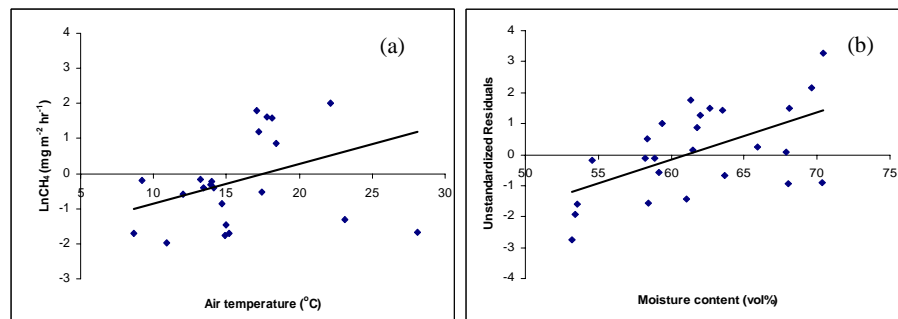


Fig. 5. (a) The effect of temperature: the relation between natural logarithm- transformed CH_4 fluxes and air temperature in April and (b) the effect of moisture; the relation between unstandardized residuals after regression with temperature, and moisture content in April.

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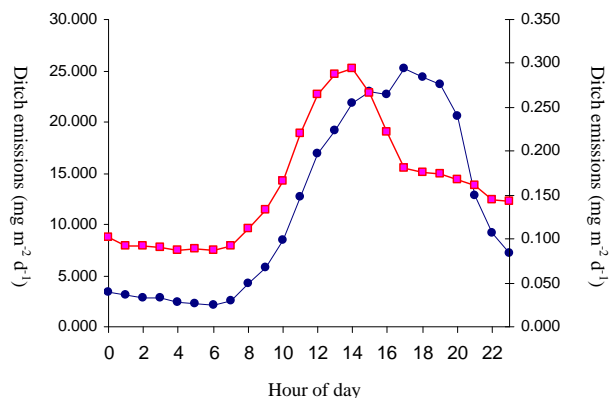


Fig. 6. Diurnal variation in regression-based estimated ditch emissions ($\text{mg m}^{-2} \text{d}^{-1}$) based on temperature during a day in winter (red squares, y-axis right), and a day in summer (blue circles, y-axis left).

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